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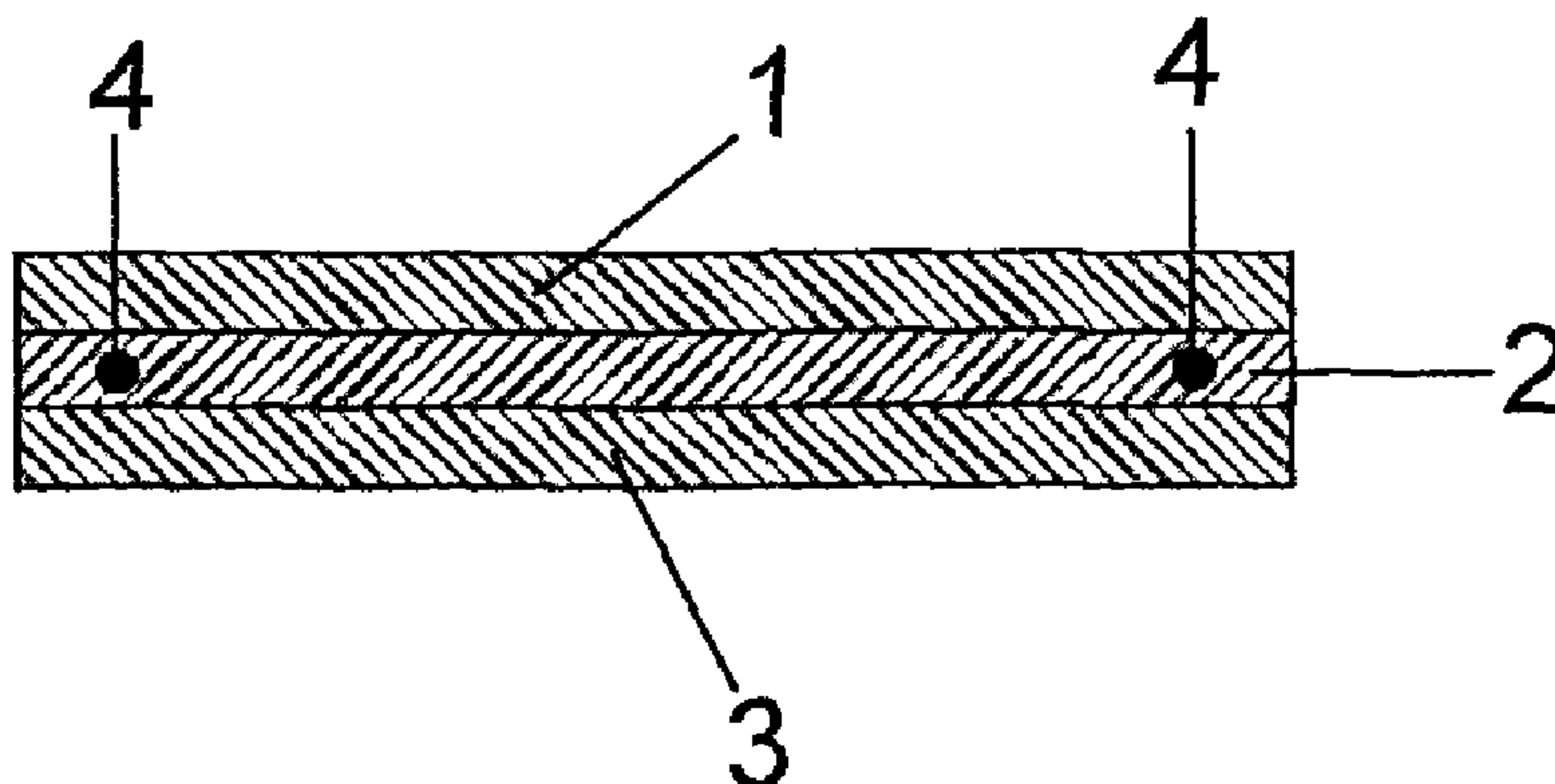
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(54) Title: TEMPERATURE-CONTROLLABLE PIPE FOR OFFSHORE APPLICATIONS



(57) Abrégé/Abstract:

A flexible pipe comprises the following layers, from the inside to the outside: an interior lining, and at least one reinforcement layer. Between two layers, there is also a further layer made of a wound tape. The tape comprises the following layers: a) a first exterior layer made of a plastics moulding composition that is not electrically conductive, b) an intermediate layer made of an electrically conductive plastics moulding composition of which the volume resistivity to IEC 60093 is in the range from  $10^{-3}$  to  $10^{10} \Omega m$ , where at least two metallic conductors have been embedded into the intermediate layer along the tape in such a way that, over the entire length, they do not touch one another, and c) a second exterior layer made of a plastics moulding composition that is not electrically conductive. The flexible pipe can be heated efficiently, and can therefore be used for conveying oil in cold regions.

23443-1057

**Abstract:**

A flexible pipe comprises the following layers, from the inside to the outside: an interior lining, and at least one reinforcement layer. Between two layers, there is also a further layer made of a wound tape. The tape comprises the following layers: a) a  
5 first exterior layer made of a plastics moulding composition that is not electrically conductive, b) an intermediate layer made of an electrically conductive plastics moulding composition of which the volume resistivity to IEC 60093 is in the range from  $10^{-3}$  to  $10^{10}$   $\Omega\text{m}$ , where at least two metallic conductors have been embedded into the intermediate layer along the tape in such a way that, over the entire length,  
10 they do not touch one another, and c) a second exterior layer made of a plastics moulding composition that is not electrically conductive. The flexible pipe can be heated efficiently, and can therefore be used for conveying oil in cold regions.

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1

**Temperature-controllable pipe for offshore applications**

The present invention relates to a temperature-controllable, flexible pipe of multilayer structure with unbonded layers. For simplicity, the term unbonded flexible pipe is  
5 used hereinafter for this type of pipe. It has high resistance to the diffusion of gases from a conveyed fluid, and can therefore be used for conveying liquid or gaseous media, and can be used with particular advantage for conveying crude oil or natural gas.

10 Unbonded flexible pipes per se are prior art. Pipes of this type comprise an interior lining, usually in the form of a plastics pipe, as barrier to the escape of the conveyed fluid, and also comprise one or more reinforcement layers on the external side of the said interior lining. The unbonded flexible pipe can comprise additional layers, for  
15 example one or more reinforcement layers on the internal side of the interior lining, in order to prevent collapse of the interior lining under high external pressure. This type of interior reinforcement is usually termed a carcass. An exterior sheath can moreover be present, in order to provide a barrier to ingress of liquid from the exterior environment into the reinforcement layers or other inner polymeric or metallic  
20 functional layers. In many instances, a thermoplastics layer, for example in the form of wound "anti-wear tapes", is introduced between the exterior reinforcement layers in order to prevent abrasion on the metal structure due to friction.

Typical unbonded flexible pipes have been described by way of example in WO 01/61232, US 6123114 and US 6085799; they have moreover been  
25 characterized in more detail in API Recommended Practice 17B "Recommended Practice for Flexible Pipe", 3rd Edition, March 2002, and in API Specification 17J "Specification for Unbonded Flexible Pipe" 2nd Edition, November 1999.

The term "unbonded" means in this context that at least two of the layers, inclusive of  
30 reinforcement layers and plastics layers, have been designed without bonding to one another. The pipe can therefore be bent, and is flexible enough to be rolled up for transport purposes.

Unbonded flexible pipes of this type are used in various embodiments in offshore  
35 applications and in various onshore applications for the transport of liquids, gases

201100176

2

and slurries. By way of example, they can be used for the transport of fluids where very high or very different water pressure prevails over the length of the pipe, by way of example taking the form of risers which run from the ocean floor up to equipment at or in the vicinity of the ocean surface, and they can also generally be used as  
5 pipes for the transport of liquids or gases between various items of equipment, or as pipes laid at great depth on the ocean floor, or as pipes between items of equipment close to the ocean surface.

The reinforcement layer(s) in conventional flexible pipes is/are mostly composed of  
10 helically arranged steel wires, steel profiles, or steel tapes, where the individual layers can have been formed with various winding angles relative to the axis of the pipe.

In the prior art, the interior lining is usually composed of a polyolefin, such as  
15 polyethylene, which can also have been crosslinked, of a polyamide, such as PA11 or PA12, or of polyvinylidene fluoride (PVDF). Alongside these, there are also known single- or multilayer linings which can also comprise layers made of other materials.

At temperatures below about 40°C, some constituents can precipitate out from crude  
20 oil. Particular importance is attached here to precipitation of waxes and sometimes of hydrates, and these can reduce the cross-sectional area of the pipe. The pipes here should be heatable in order to inhibit this phenomenon and in order to provide the transport function even when temperatures are low. There are various ways of heating pipes of this type.

25 WO 91/18231 describes a heatable flexible pipe system which comprises electrically conductive cables which have been connected to an electrically conductive source of current and generate heat by the principle of resistance heating. Disadvantages of this concept are complicated design and irregularity of temperature control over the  
30 entire length.

WO 97/20162 moreover describes a flexible pipe system where a flexible interior pipe is surrounded by a plurality of smaller pipes. These can be utilized for the transport of process media or current. Another conceivable method for temperature-  
35 control of the pipe system would use passage of a temperature-controlled medium.

23443-1057

3

Figure 1 is a cross-sectional view of a tape according to an embodiment of the invention; and

Figure 2 is a cross-sectional view of a tape according to another embodiment of the invention.

The disadvantages of this concept are likewise complicated design, heat losses, and irregular temperature-control over the entire length.

- 5 Other applications (WO 92/11487, WO 85/04941, WO 2000/66934, WO 2000/66935 and WO 2001/07824) concern the topic of thermal insulation as a passive method of stabilization of the temperature of the media. However, a problem here is the compressibility of the foamed structures often used. This can reduce the insulation effect at large depths under water and at the high external pressures associated therewith.
- 10 WO 2006/097765, WO 2006/090182, US 2008202616 and US 4 874 925 describe another heating method. This involves a multilayer pipe in which by way of example two conductors are present, embedded in a conductive layer and displaced by 180° with respect to one another along the pipe. Current flowing from one conductor to the other causes heating within the conductive layer. An important factor for uniform heating is connection to, or uniform contact of the
- 15 conductor with, the conductive layer. The conductive layer has external thermal and optionally electrical insulation. An advisable or necessary feature is an additional layer inside towards the crude oil, for electrical insulation.

WO 2008/005829 describes heatable pipes in the automobile sector, where these can comprise an electrically conductive polymer layer; this layer acts as a resistance heating system.

- 20 Some embodiments of the invention may provide a flexible pipe of multilayer structure in which the conveyed medium can be electrically heated, while the structure is not significantly more expensive. In some embodiments it should be possible to heat the pipe in a targeted manner only in the pipe sections where this is specifically required.

- Some embodiments disclosed herein relate to a flexible pipe comprising the following layers, from
- 25 the inside to the outside:

- an interior lining,
- at least one reinforcement layer, and
- optionally an exterior sheath,

201100176

4

an additional factor being that between two layers there is a further layer made of a wound tape which comprises the following layers:

- 5 a) a first exterior layer (1) made of a plastics moulding composition that is not electrically conductive,
- b) an intermediate layer (2) made of an electrically conductive plastics moulding composition of which the volume resistivity to IEC 60093 is in the range from  $10^{-3}$  to  $10^{10}$   $\Omega\text{m}$ , preferably in the range from  $10^{-2}$  to  $10^8$   $\Omega\text{m}$ , particularly preferably in the  
 10 range from  $10^{-1}$  to  $10^7$   $\Omega\text{m}$  and with particular preference in the range from  $10^0$  to  $10^6$   $\Omega\text{m}$ , where at least two metallic conductors (4) have been embedded into the intermediate layer along the tape in such a way that, over the entire length, they do not touch one another, and also
- c) a second exterior layer (3) made of a plastics moulding composition that is not  
 15 electrically conductive.

The interior lining is usually a plastics pipe which provides a barrier to escape of the fluid conveyed. This pipe can, as a function of performance requirements, comprise a single layer or else can be composed of a plurality of layers made of respectively  
 20 different moulding compositions. In this case it is by way of example a two-layer, three-layer, or four-layer system, or else in particular instances is composed of even more layers. Linings of this type are prior art. In another embodiment, the interior lining can also be composed of a corrugated, thin-walled metal pipe.

25 The reinforcement layer or layers is/are usually composed of helically arranged steel wires, steel profiles or steel tapes. The design of the said reinforcement layers is prior art. It is preferable that the structure of at least one of these reinforcement layers is such that it withstands the internal pressure, and that the structure of at least one other of these reinforcement layers is such that it withstands tensile forces.

30 There are usually more than two reinforcement layers present. Adjacent to the reinforcement layers in most cases there is an exterior sheath, usually in the form of a pipe or flexible tube made of a thermoplastic moulding composition or made of an elastomer.

35 In one possible embodiment, there is a carcass on the interior side of the interior

201100176

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lining of the unbonded flexible pipe. These carcasses and design thereof are prior art. In another possible embodiment, the unbonded flexible pipe comprises no carcass, especially when it is not intended for operation under high external pressures.

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Suitable materials for the electrically conductive plastics moulding composition and for the two plastics moulding compositions which are not electrically conductive are, independently of one another, moulding compositions by way of example based on olefinic polymers, on polyamides, on fluoropolymers, on polyethylene 2,6-naphthalate, on polybutylene 2,6-naphthalate, on polyphenyl sulphone, on polyarylene ether ketone, on polyphenylene sulphide, or on a polyarylene ether ketone/polyphenylene sulphide blend.

The olefinic polymer can firstly be a polyethylene, in particular a high-density polyethylene (HDPE), or an isotactic or syndiotactic polypropylene. The polypropylene can be a homo- or copolymer, for example with ethylene or 1-butene as comonomer, and it is possible here to use either random or block copolymers. The polypropylene can moreover also have been impact-modified, for example as in the prior art by means of ethylene-propylene rubber (EPM) or EPDM. The syndiotactic polystyrene that can also be used according to the invention can be produced in a known manner by metallocene-catalysed polymerization of styrene.

The polyamide can be produced from a combination of diamine and dicarboxylic acid, from an  $\omega$ -aminocarboxylic acid, or from the corresponding lactam. In principle it is possible to use any polyamide, for example PA6 or PA66. In one preferred embodiment, the monomer units of the polyamide comprise on average at least 8, at least 9 or at least 10 carbon atoms. In the case of mixtures of lactams, it is the arithmetic average that is considered here. In the case of a combination of diamine and dicarboxylic acid, the arithmetic average of the number of carbon atoms of diamine and dicarboxylic acid in this preferred embodiment must be at least 8, at least 9 or at least 10. Examples of suitable polyamides are: PA610 (which can be produced from hexamethylenediamine [6 carbon atoms] and sebacic acid [10 carbon atoms], the average number of carbon atoms in the monomer units here therefore being 8), PA88 (which can be produced from octamethylenediamine and 1,8-octanedioic acid), PA8 (which can be produced from caprylolactam), PA612, PA810,

201100176

6

PA108, PA9, PA613, PA614, PA812, PA128, PA1010, PA10, PA814, PA148, PA1012, PA11, PA1014, PA1212 and PA12. The production of the polyamides is prior art. It is also possible, of course, to use copolyamides based on these materials, and it is also optionally possible here to make concomitant use of monomers such as caprolactam.

Advantageously, it is also possible to use, as polyamide, a semiaromatic polyamide in which from 5 to 100 mol% of the dicarboxylic acid content derives from aromatic dicarboxylic acid having from 8 to 22 carbon atoms and which has a crystallite melting point  $T_m$  of at least 260°C, preferably of at least 270°C and particularly preferably of at least 280°C. These polyamides are usually termed PPA. They can be produced from a combination of diamine and dicarboxylic acid, optionally with addition of an  $\omega$ -aminocarboxylic acid or of the corresponding lactam. Examples of suitable types are PA66/6T, PA6/6T, PA6T/MPMDT (MPMD stands for 2-methylpentamethylenediamine), PA9T, PA10T, PA11T, PA12T, PA14T and also copolycondensates of these last types with an aliphatic diamine and with an aliphatic dicarboxylic acid or with an  $\omega$ -aminocarboxylic acid or, respectively, a lactam.

The moulding composition can comprise, alongside polyamide, further components, e.g. impact modifiers, other thermoplastics, plasticizers and other conventional additives. The only requirement is that the polyamide forms the matrix of the moulding composition.

The fluoropolymer can by way of example be a polyvinylidene fluoride (PVDF), an ethylene-tetrafluoroethylene copolymer (ETFE), an ETFE modified with the aid of a tercomponent such as propene, hexafluoropropene, vinyl fluoride or vinylidene fluoride (for example EFEP), an ethylene-chlorotrifluoroethylene copolymer (E-CTFE), a polychlorotrifluoroethylene (PCTFE), a chlorotrifluoroethylene-perfluorinated alkyl vinyl ether-tetrafluoroethylene copolymer (CPT), a tetrafluoroethylene-hexafluoropropene copolymer (FEP) or a tetrafluoroethylene-perfluorinated alkyl vinyl ether copolymer (PFA). It is also possible to use copolymers based on vinylidene fluoride which comprise up to 40% by weight of other monomers, examples being trifluoroethylene, chlorotrifluoroethylene, ethylene, propene and hexafluoropropene.

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201100176

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Polyphenyl sulphone (PPSU) is produced by way of example by Solvay Advanced Polymers under trade mark Radel®. It can be produced by nucleophilic substitution from 4,4'-dihydroxybiphenyl and 4,4'-dihydroxydiphenyl sulphone. Another particular suitable material is a PPSU/fluoropolymer blend, for example a PPSU/PTFE blend.

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The polyarylene ether ketone which can likewise be used comprises units of the formulae



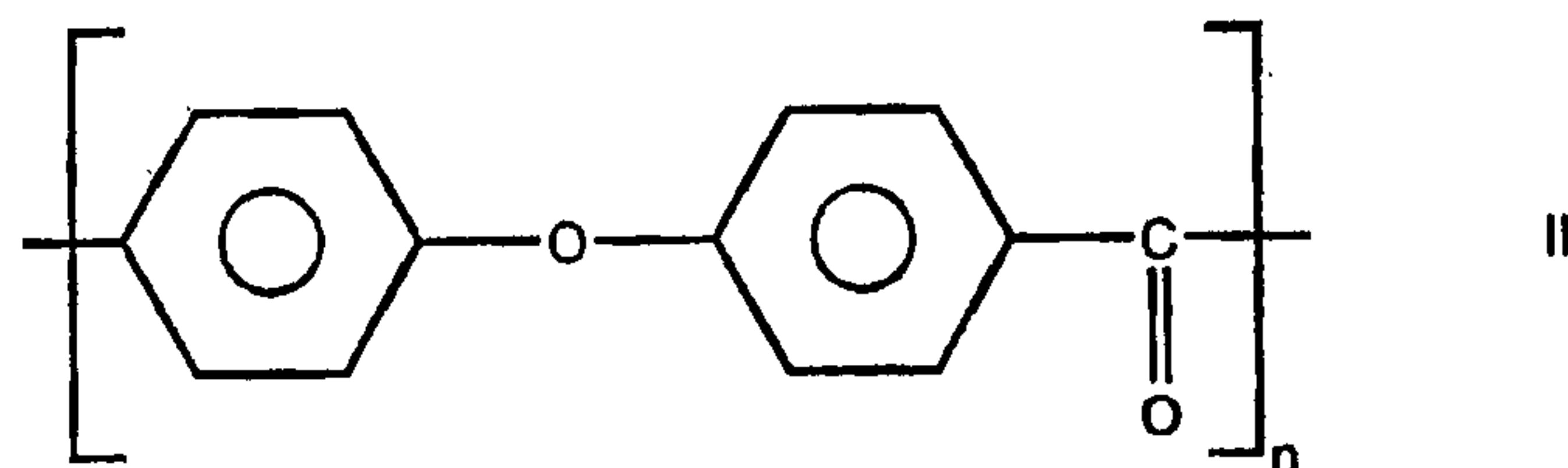
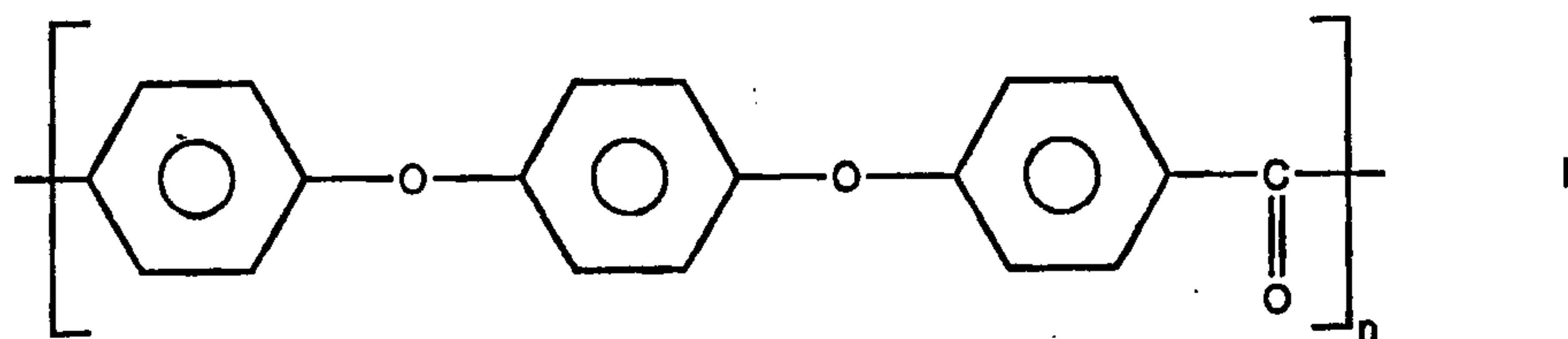
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where Ar and Ar' are a divalent aromatic moiety, preferably 1,4-phenylene, 4,4'-biphenylene, or else 1,4-, 1,5- or 2,6-naphthylene. X is an electron-withdrawing group, preferably carbonyl or sulphonyl, while Y is another group, such as O, S, CH<sub>2</sub>, isopropylidene or the like. At least 50%, preferably at least 70% and particularly preferably at least 80% of the groups X here are a carbonyl group, while at least 50%, preferably at least 70% and particularly preferably at least 80% of the groups Y are composed of oxygen.

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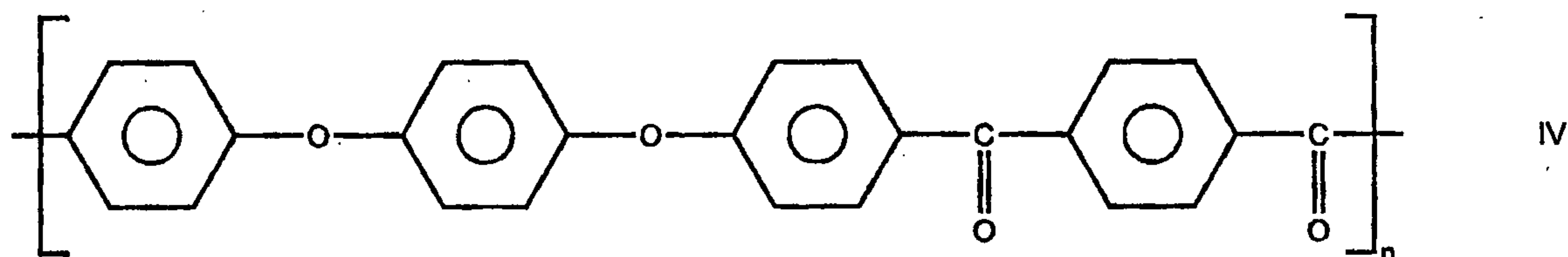
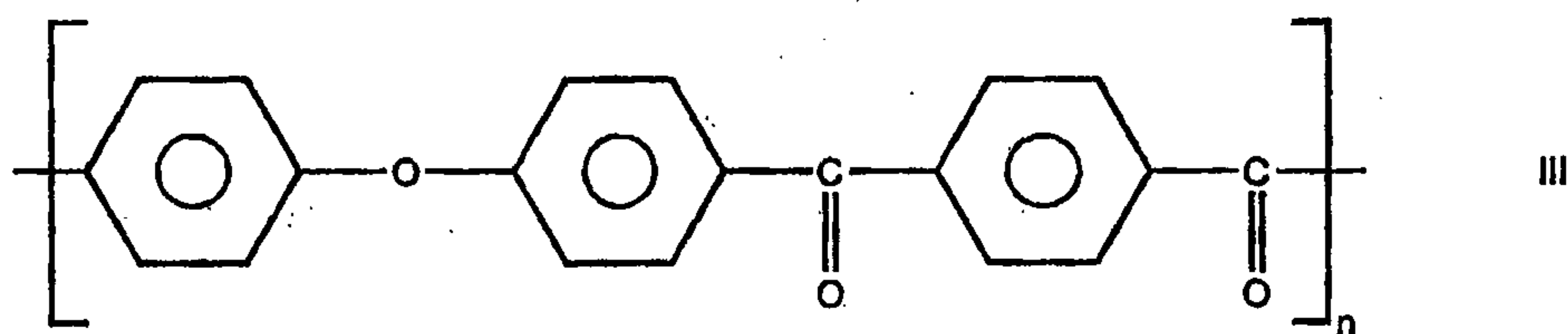
In the preferred embodiment, 100% of the groups X are composed of carbonyl groups and 100% of the groups Y are composed of oxygen. In this embodiment, the polyarylene ether ketone can by way of example be a polyether ether ketone (PEEK; formula I), a polyether ketone (PEK; formula II), a polyether ketone ketone (PEKK; formula III) or a polyether ether ketone ketone (PEEKK; formula IV), but other arrangements of the carbonyl groups and oxygen groups are naturally also possible.

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201100176

8



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The polyarylene ether ketone is semicrystalline, and this is seen by way of example in the DSC analysis where a crystallite melting point  $T_m$  is observed, the order of magnitude of which is in most instances around 300°C or thereabove.

10 The polyphenylene sulphide comprises units of the formula



and it is preferably composed of at least 50% by weight of the said units, or at least  
 15 70% by weight or at least 90% by weight. The remaining units can be those stated above for the case of the polyarylene ether ketone, or tri- or tetra-functional branching units which result from the concomitant use of, for example, trichlorobenzene or tetrachlorobenzene during synthesis. Polyphenylene sulphide is available commercially in a wide variety of types or moulding compositions.

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In the case of the polyarylene ether ketone/polyphenylene sulphide blends, the two components can be present in any conceivable mixing ratio, and the range of constitution therefore continuously covers the entire range from pure polyarylene ether ketone to pure polyphenylene sulphide. The blend generally comprises at least  
 25 0.01% by weight of polyarylene ether ketone and, respectively, at least 0.01% by weight of polyphenylene sulphide.

201100176

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The plastics moulding compositions can comprise the usual auxiliaries and additives, and also optionally other polymers, an example in the case of the polyarylene ether ketone being fluoropolymers, such as PFA (a copolymer of tetrafluoroethylene and perfluorinated vinyl methyl ether), polyimide, polyetherimide, LCP, such as liquid-crystalline polyesters, polysulphone, polyether sulphone, polyphenyl sulphone, polybenzimidazole (PBI) or other high-temperature-resistant polymers, and an example in the case of the polyphenylene sulphide being copolymers and, respectively, terpolymers of ethylene with polar comonomers, and in the case of the semiaromatic polyamide an aliphatic polyamide. The polyamide moulding composition can by way of example also comprise a hydrolysis stabilizer, a plasticizer and, respectively, impact modifiers. The moulding composition can moreover comprise a lubricant, such as molybdenum disulphide, hexagonal boron nitride or PTFE. The proportion of the main polymers, or else, in the preferred case, the proportion of olefinic polymer, polyamide, fluoropolymer, polyphenyl sulphone, polyarylene ether ketone, polyphenylene sulphide or polyarylene ether ketone/polyphenylene sulphide blend in the moulding composition is at least 50% by weight, preferably at least 60% by weight, particularly preferably at least 70% by weight, with particular preference at least 80% by weight and very particularly preferably at least 90% by weight.

20

The electrical conductivity of the intermediate layer according to b) is achieved in a known manner, for example through addition of conductive or other carbon black, graphite powder and/or carbon nanotubes (CNTs) or graphite fibrils.

25 The tape can, if desired, also comprise further layers alongside the layers according to a), b) and c), for example an adhesion promoter layer between the layers according to a) and b) and/or an adhesion promoter layer between the layers according to b) and c).

30 The cross-sectional area of the tape can by way of example be of rectangular or rounded shape.

At the edges of the tape, the individual layers can have uncovered edges (Figure 1), or the layers according to a) and c) can have been bonded to one another at that

201100176

location (Figure 2), in order to achieve the best possible electrical insulation in relation to the reinforcement layers.

The metallic conductors embedded into the layer according to b) can be connected to a source of electrical current. The potential difference then present between the individual conductors causes a current to flow through the electrically conductive intermediate layer; the said layer therefore functions as resistance heating system. The voltage applied here can be direct voltage or alternating voltage. In order to reduce the risk of failure, it can be advantageous to have more than two metallic conductors embedded into the intermediate layer according to b), for example three, four, five or six. The metallic conductors must be corrosion-resistant with regard to the conveyed fluid and its constituents.

The thickness of the tape is usually in the range from 0.2 to 5 mm, preferably in the range from 0.4 to 5 mm and particularly preferably in the range from 0.5 to 4 mm. The thickness of the intermediate layer according to b) here is generally in the range from 0.1 to 3 mm, preferably in the range from 0.2 to 2.5 mm and particularly preferably in the range from 0.3 to 2 mm, while the thickness of each of the two exterior layers according to a) and c) is generally in the range from 0.05 to 1.5 mm, preferably in the range from 0.1 to 1 mm and particularly preferably in the range from 0.1 to 0.5 mm.

The width of the tape depends on the diameter of the pipe. Usual widths are in the range from about 20 mm to about 700 mm, preferably in the range from about 30 mm to about 500 mm and particularly preferably in the range from about 40 mm to about 300 mm.

The tape is wound helically under tension onto a layer situated further inwards, and this winding can be carried out either with edges abutted or with overlap. In the latter case, the overlapping locations of the tape can be fused after the winding process. This can be achieved either by hot gas welding, by contact with a heating element, by means of a (gas) flame or by irradiation with electromagnetic radiation in the UV, visible or IR spectral range. In principle, spot welding is sufficient to fix the tape; however, preference is given to continuous production of an uninterrupted welded seam. Another possibility, of course, is that the full surface of the tape is welded in

201100176

11

the overlapping regions. For the fusion process it is advantageous for the softening range of the moulding composition in the layers according to a) and c) to be lower than the softening range of the moulding composition in the layer according to b).

- 5 In order to reduce the risk of failure, it is also possible to wind, alongside one another or over one another, a plurality of tapes, each of which possesses its own electrical circuit. It is moreover possible that the flexible pipe also possesses a plurality of such layers made of wound tape and separated from one another by a reinforcement layer.

10

- The layer made of wound tape can also simultaneously function as an anti-wear layer. In the prior art, anti-wear tapes are placed between the reinforcement layers made of steel, in order to prevent abrasion of the reinforcement layers. The primary result of this is abrasion of the tape. This abrasion must where appropriate be  
15 considered during design, in order to ensure that the electrically conductive intermediate layer is insulated over the entire lifetime of the flexible pipe. For the layers according to a) and c), it is therefore preferable to use moulding compositions which have particularly good tribological properties.

- 20 When the moulding composition of the layer according to b) comprises, as electrically conductive additive, (conductive) carbon black, the heating system can utilize the PTC (positive temperature coefficient) effect. This effect provides an intrinsic safety feature, since it restricts temperature increase at constant voltage, because conductivity falls as the system becomes hotter. This can prevent thermal  
25 degradation of the pipe or of the medium to be transported.

- According to the invention, it is also possible that the tape is placed only in specific sections of the pipe. It is possible to design this to be conductive in the region where specific heating is required, and to introduce, instead of this, in other regions of the  
30 pipe, by way of example a conventional anti-wear tape.

- The flexible pipe can optionally comprise, alongside the layers described here, further layers, for example unidirectionally reinforced or textile-reinforced polymer layers, and it is possible here to use carbon fibre reinforcement with good thermal  
35 conductivity, or an externally situated thermal insulation layer.

201100176

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With the aid of the invention it is possible to heat the pipe over its entire length or in selected sections, in order to prevent precipitation. Thermal degradation of the pipe system and of the transported medium can thus be avoided. Technical realization is simple, since no complicated additional technical parts are needed, and the structure per se of the pipe is not altered. The pipe of the invention can therefore be heated efficiently to the extent that it can also be used for conveying oil in cold regions, for example in the Arctic. Another possibility is use over long distances in deep-sea locations, where the conveyed medium is prevented from falling below the critical temperature discussed above.

23443-1057

13

CLAIMS:

1. Flexible pipe comprising the following layers, from the inside to the outside:

- an interior lining, and

5 - at least one reinforcement layer,

where, between two layers, there is also a further layer made of a wound tape,

wherein

the tape comprises the following layers:

10 a) a first exterior layer made of a plastics moulding composition that is not electrically conductive,

b) an intermediate layer made of an electrically conductive plastics moulding composition of which the volume resistivity to IEC 60093 is in the range from  $10^{-3}$  to  $10^{10} \Omega m$ , where at least two metallic conductors have been embedded into the

15 intermediate layer along the tape in such a way that, over the entire length, they do not touch one another, and

c) a second exterior layer made of a plastics moulding composition that is not electrically conductive.

2. Flexible pipe according to claim 1,

20 wherein

the electrically conductive plastics moulding composition of the layer according to b) comprises conductive carbon black, graphite powder and/or graphite fibrils.

23443-1057

14

3. Flexible pipe according to any one of claims 1 and 2,

wherein

the thickness of the tape is in the range from 0.2 to 5 mm, where the thickness of the layer according to b) is in the range from 0.1 to 3 mm and the

5 thickness of each of the two exterior layers according to a) and c) is in the range from 0.05 to 1.5 mm.

4. Flexible pipe according to any one of claims 1 to 3, wherein the reinforcement layer or layers is/are composed of helically arranged steel wires, steel profiles or steel tapes.

10 5. Use of the flexible pipe according to any one of claims 1 to 4 for conveying crude oil.

6. Method for heating a flexible pipe according to any one of claims 1 to 4,

wherein

15 the metallic conductors embedded in the intermediate layer are attached to a source of electrical current in such a way that a current flows through the electrically conductive intermediate layer.

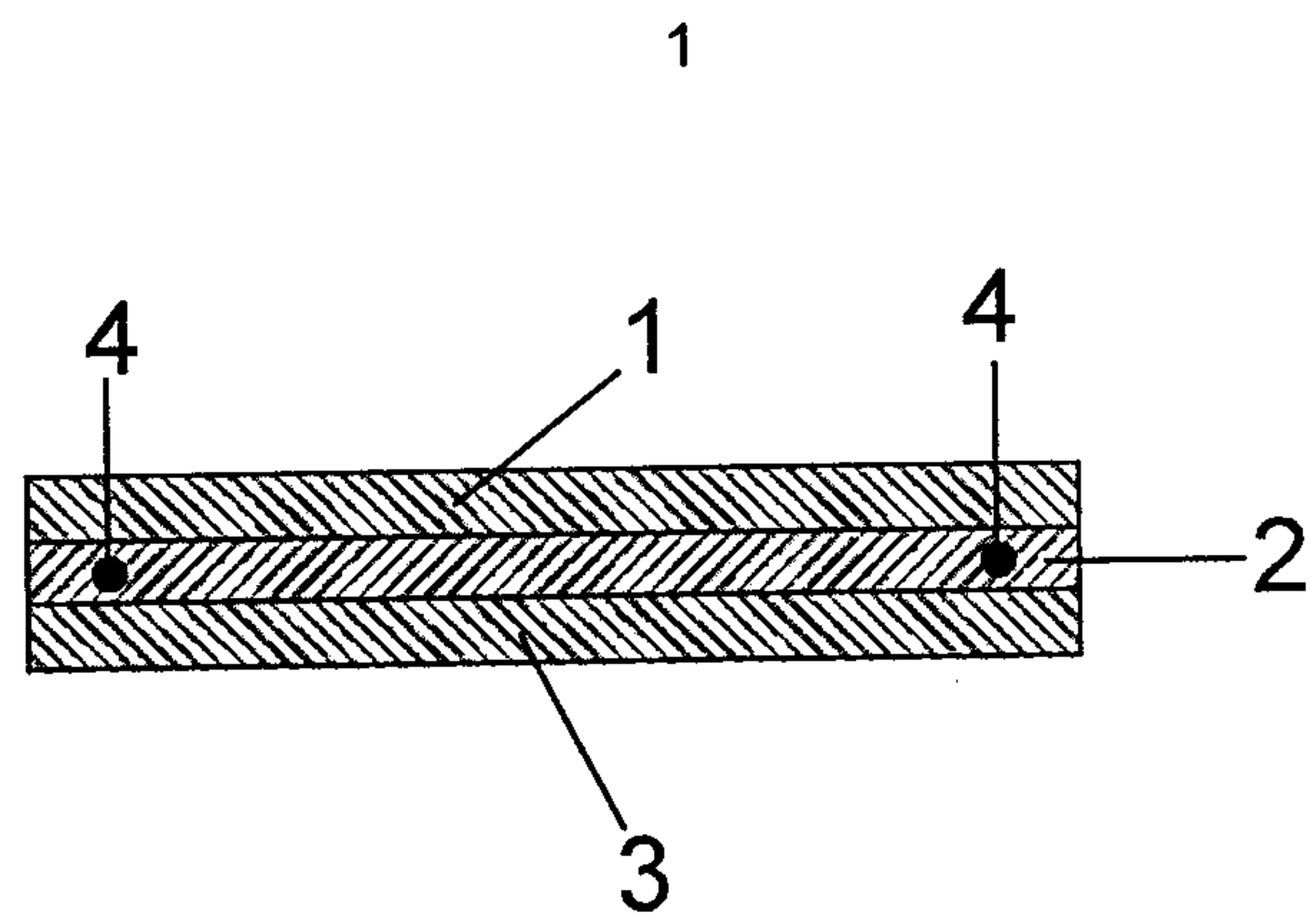


Fig. 1

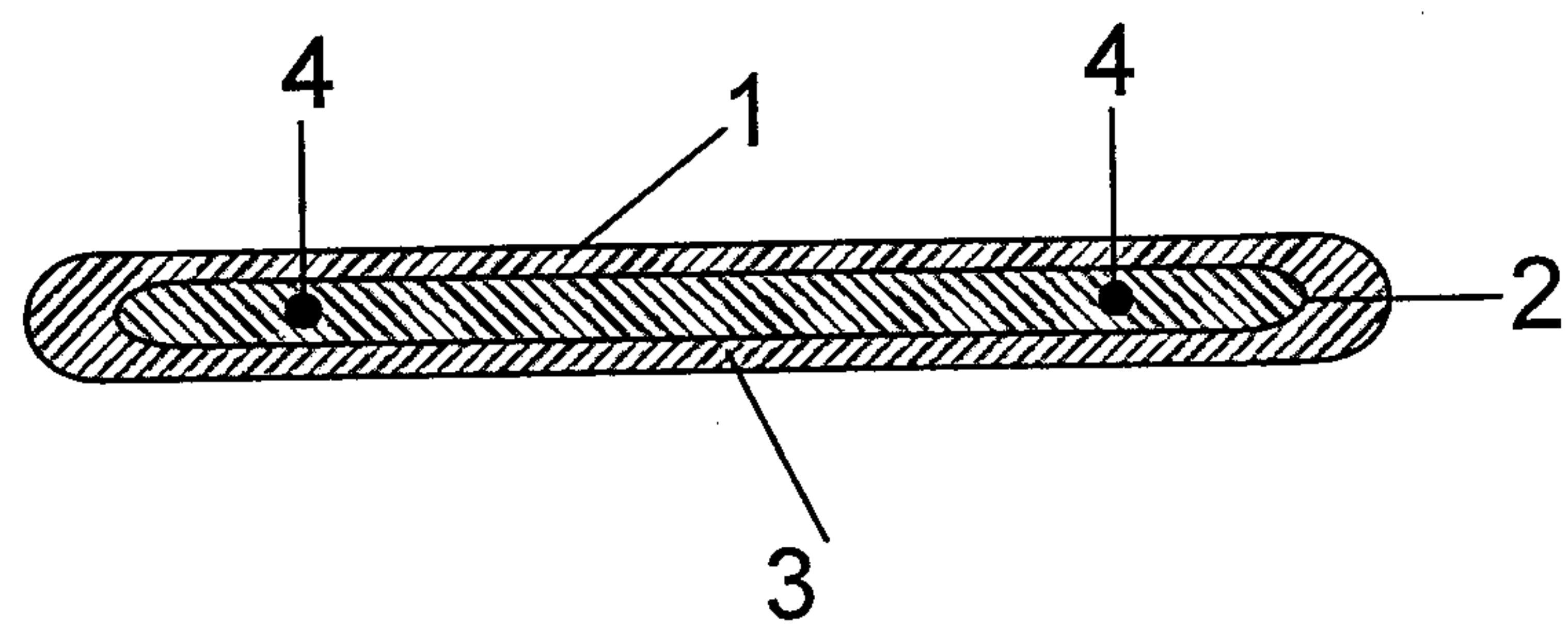


Fig. 2

